Wind Speed and Significant Wave Height under Hurricane Irma derived from Sentinel-1 and RADARSAT-2 SAR data

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AGU, Dec, 13, 2017
New Orleans

DLR

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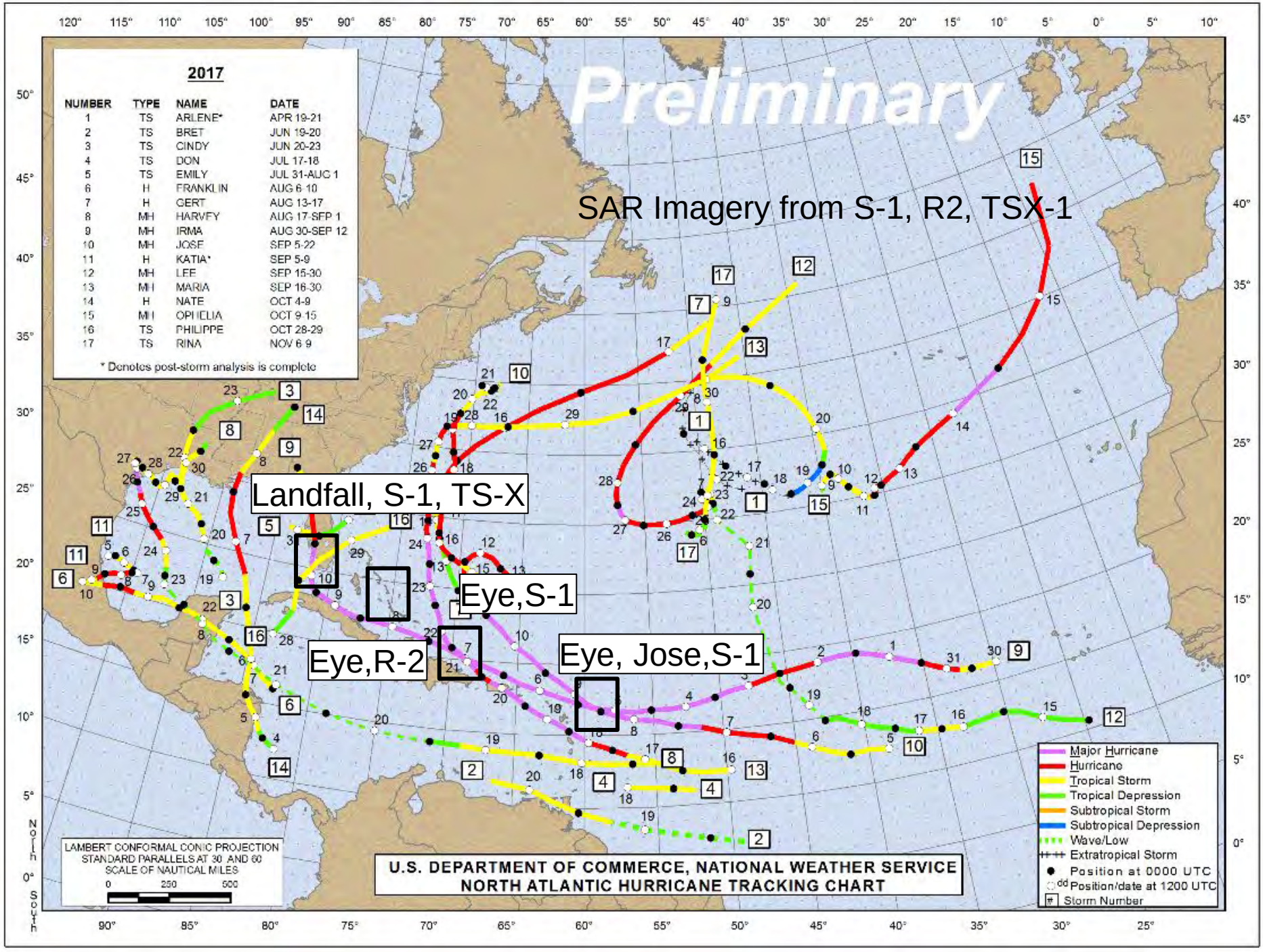
Introduction

- X-band (TerraSAR-X) and C-band (Sentinel-1, RadarSAT-2) SAR Images are used to image the Sea Surface under 2017 Hurricanes Irma and Jose
- Wind Speed and Sea State Parameters are derived using empirical algorithms
- Wind Speed measurements from the radar polarizations HH and VV saturate at low 20 -30 m/sec depending on range, one can use HV channel to overcome this problem
- Determine Significant Wave Height using empirical algorithms
- Use X-band Data to analyze rain effects
- Sentinel data can be downloaded for free on ESAs website, TerraSAR-X available by science AO


2017
NUMBER TYPE NAME DATE
1 TS ARLENE* APR 19-21
2 TS BRET JUN 19-20
3 TS CINDY JUN 20-23
4 TS DON JUL 17-18
5 TS EMILY JUL 31-AUG 1
6 H FRANKLIN AUG 6-10
7 H GERT AUG 13-17
8 MH HARVEY AUG 17-SEP 1
9 MH IRMA AUG 30-SEP 12
10 MH JOSE SEP 5-22
11 H KATIA* SEP 5-9
12 MH LEE SEP 15-30
13 MH MARIA SEP 16-30
14 H NATE OCT 4-9
15 MH OPHELIA OCT 9-15
16 TS PHILIPPE OCT 28-29
17 TS RINA NOV 6-9
* Denotes post-storm analysis is complete
Preliminary
SAR Imagery from S-1, R2, TSX-1
Landfall, S-1, TS-X
Eye,S-1
Eye,R-2
Eye, Jose,S-1
LAMBERT CONFORMAL CONIC PROJECTION
STANDARD PARALLELS AT 30 AND 60
SCALE OF NAUTICAL MILES
0 250 500
U.S. DEPARTMENT OF COMMERCE, NATIONAL WEATHER SERVICE
NORTH ATLANTIC HURRICANE TRACKING CHART
Major Hurricane
Hurricane
Tropical Storm
Tropical Depression
Subtropical Storm
Subtropical Depression
Wave/Low
Extratropical Storm
Position at 0000 UTC
dd Position/date at 1200 UTC
Storm Number

20kmx20km

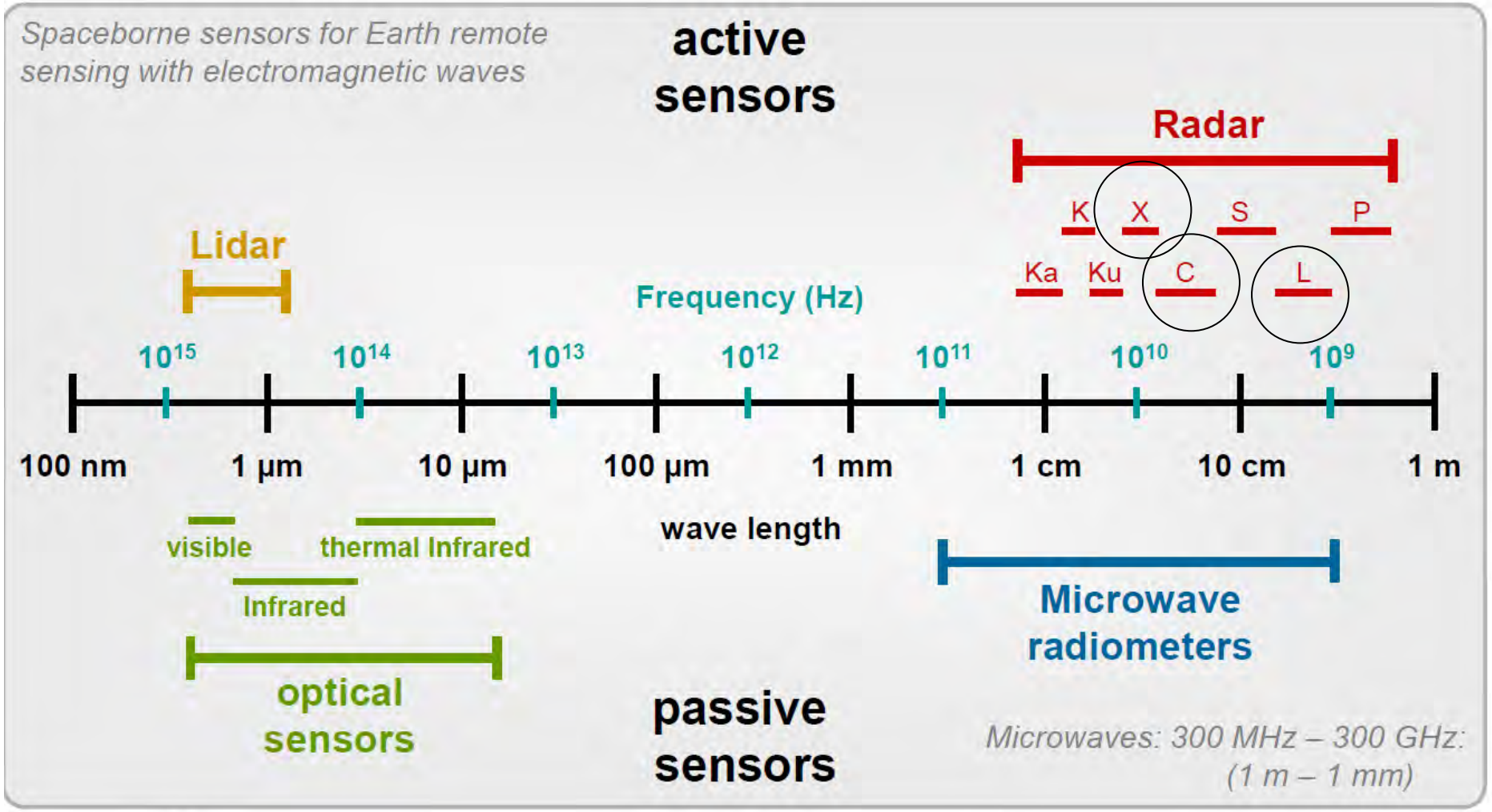
In 2017 several SAR images of hurricane acquired by ESA‘s project SHOC

Dominican Republic
2017-09-07 10:30

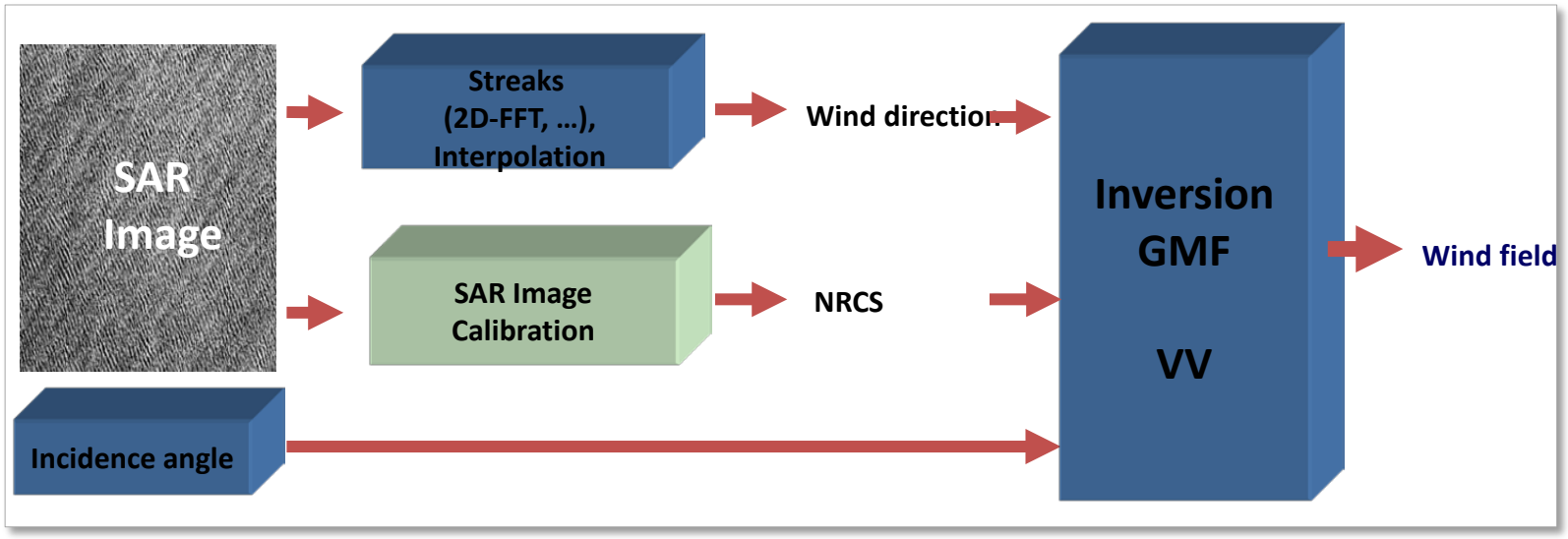
SENTINEL-1 VV

Hurrican e Irma from SAR

Radar and Optical Sensors



SAR Sea Surface Wind Retrieval from Co Polarization (VV, HH)



Geophysical Model Function (GMF): $\sigma_0 = B_0(v,\theta)(1 + B_1(v,\theta)\cos\phi + B_2(v,\theta)\cos 2\phi)$

Polarization Ratio Sigma$_0$ exponential

Radar band	GMF	Spaceborne SAR Sensors
C-band (5.6GHz)	CMOD4,CMOD5/5N	ERS/SAR,ENVISAT/ASAR, RADARSAT-1/2
L-band (1.3GHz)	LMOD1/2	JERS-1, ALOS PALSAR-1/2
X-band (9.6GHz)	**XMOD**	TerraSAR-X/TanDEM-X, Cosmo-SkyMed

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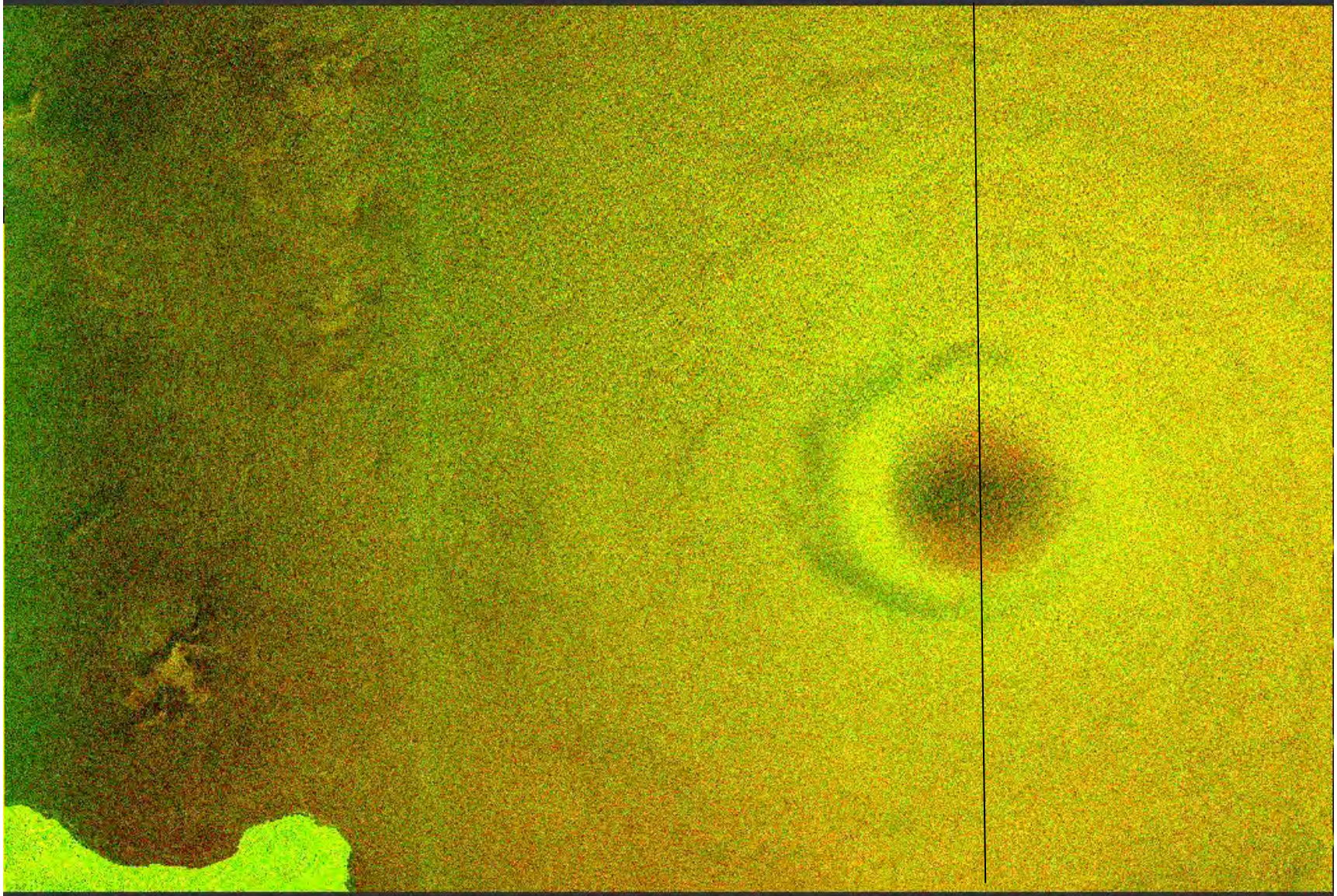
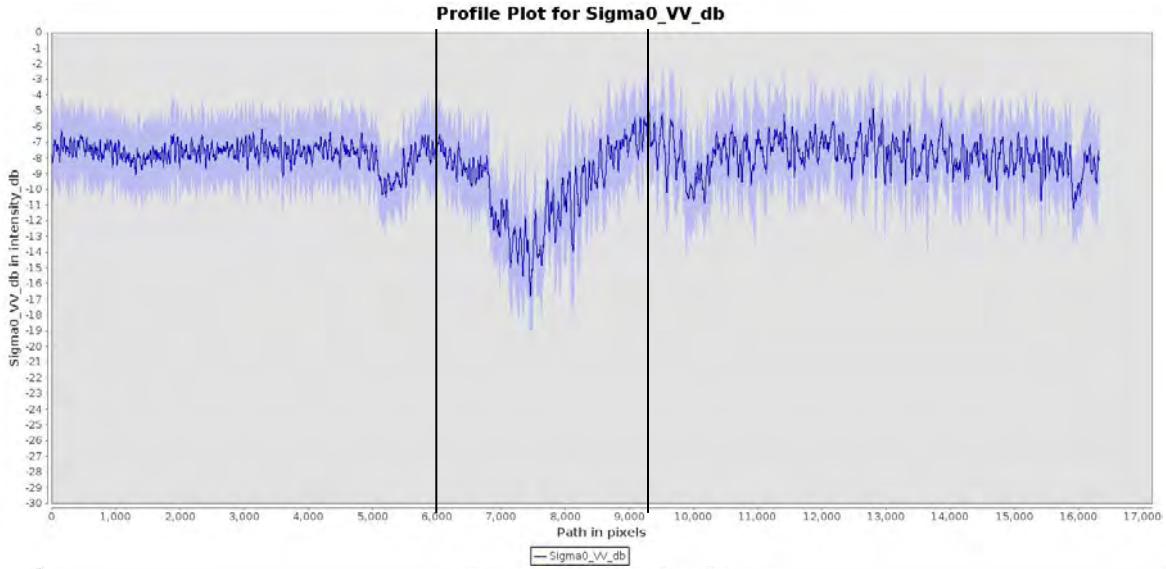
Sentinel-1, Combination of Channels Sigma 0 , VV, VH



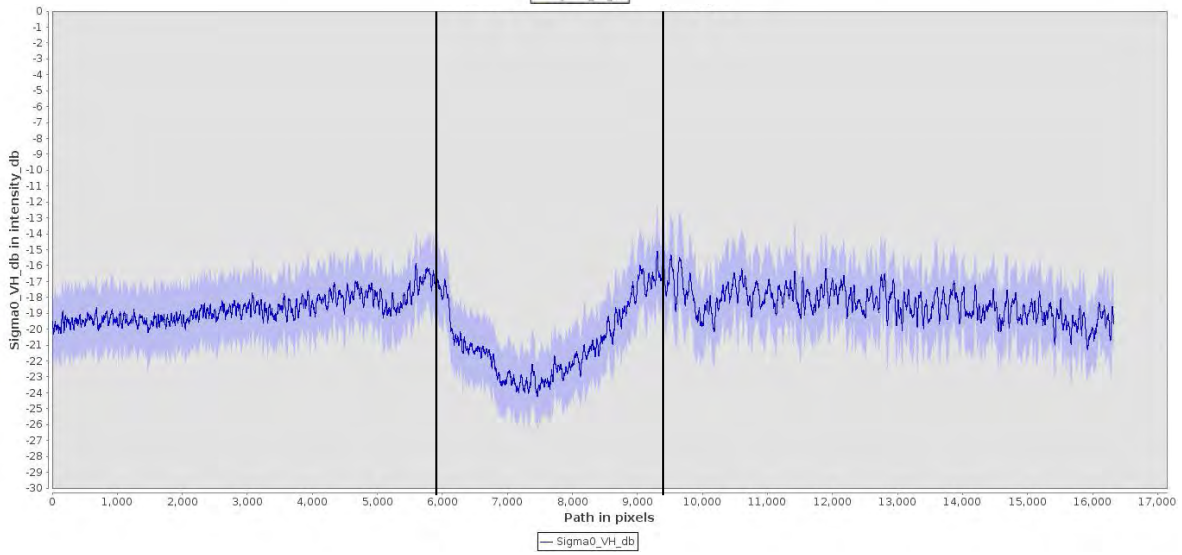
17-09-07 10:30 UTC Hurricane IRMA

Cut through the eye Sigma$_0$ at constant range

Saturates at -7dB

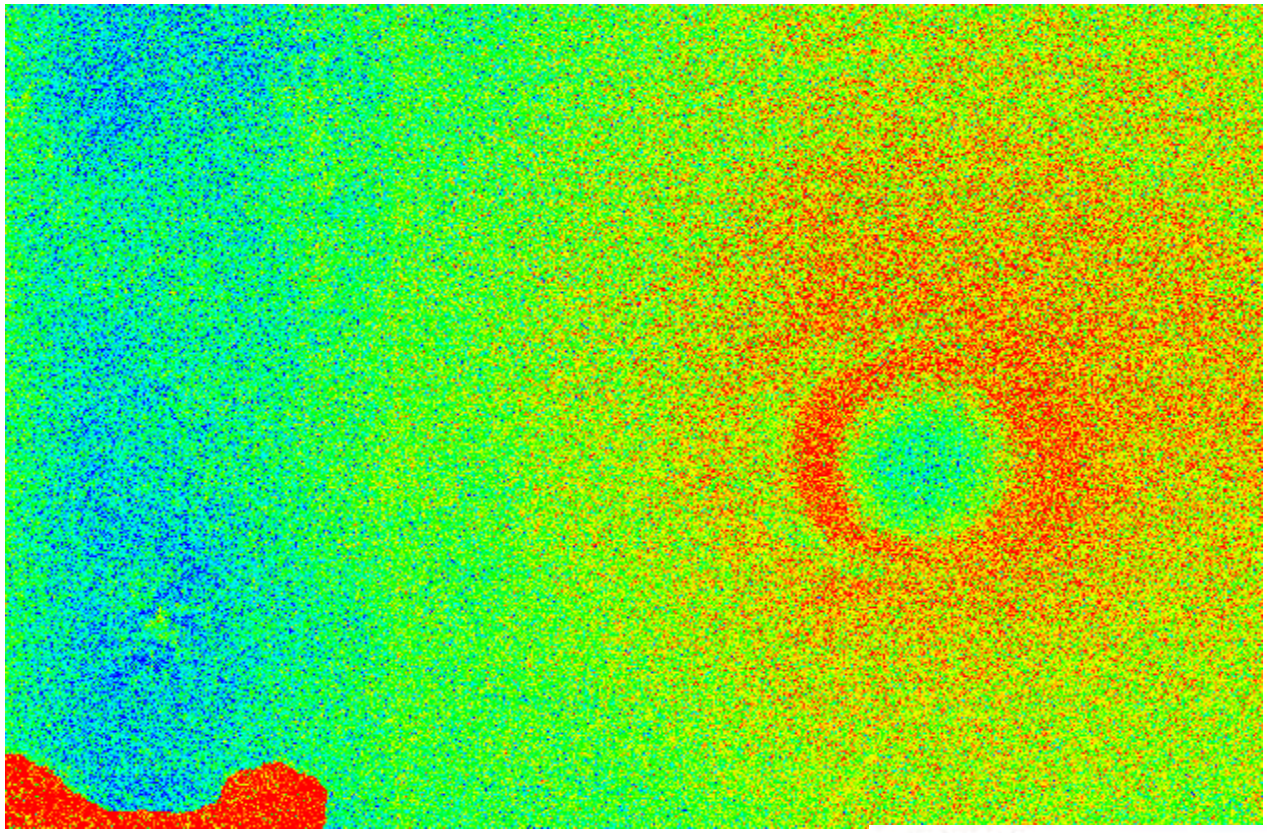


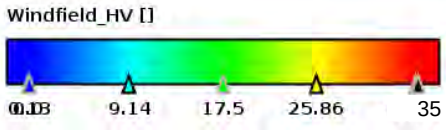
VV



VH

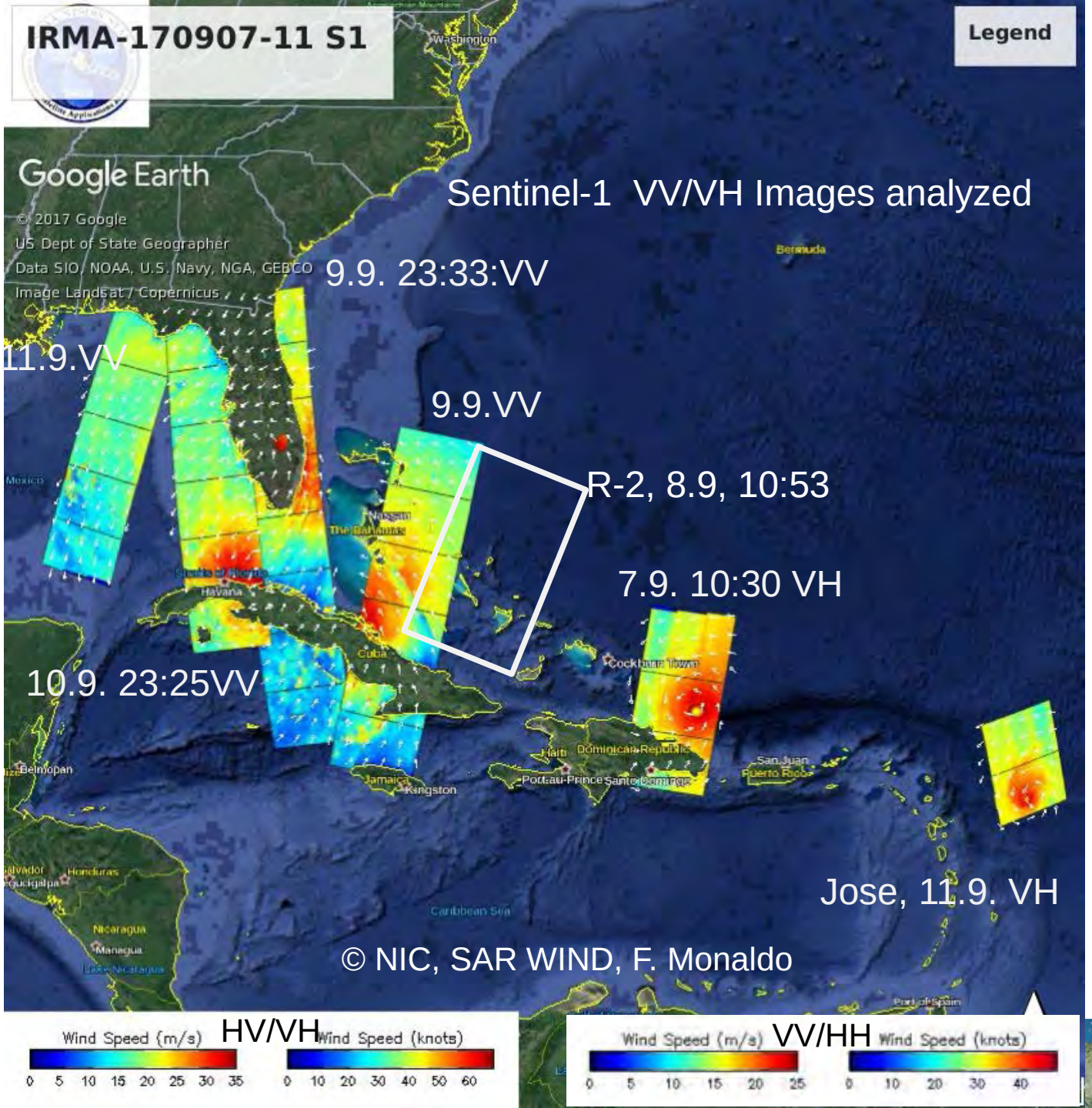
Wind Speed U_{10} derived from VH using empirical Algorithm



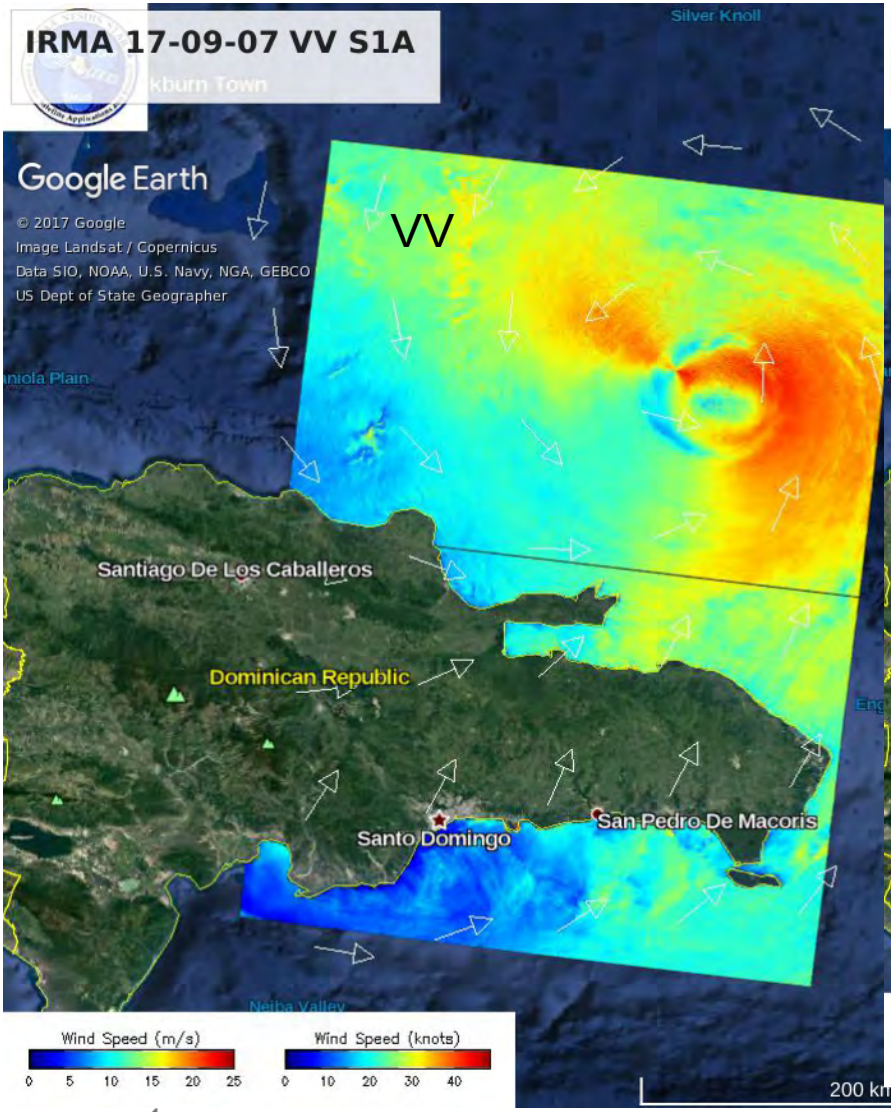


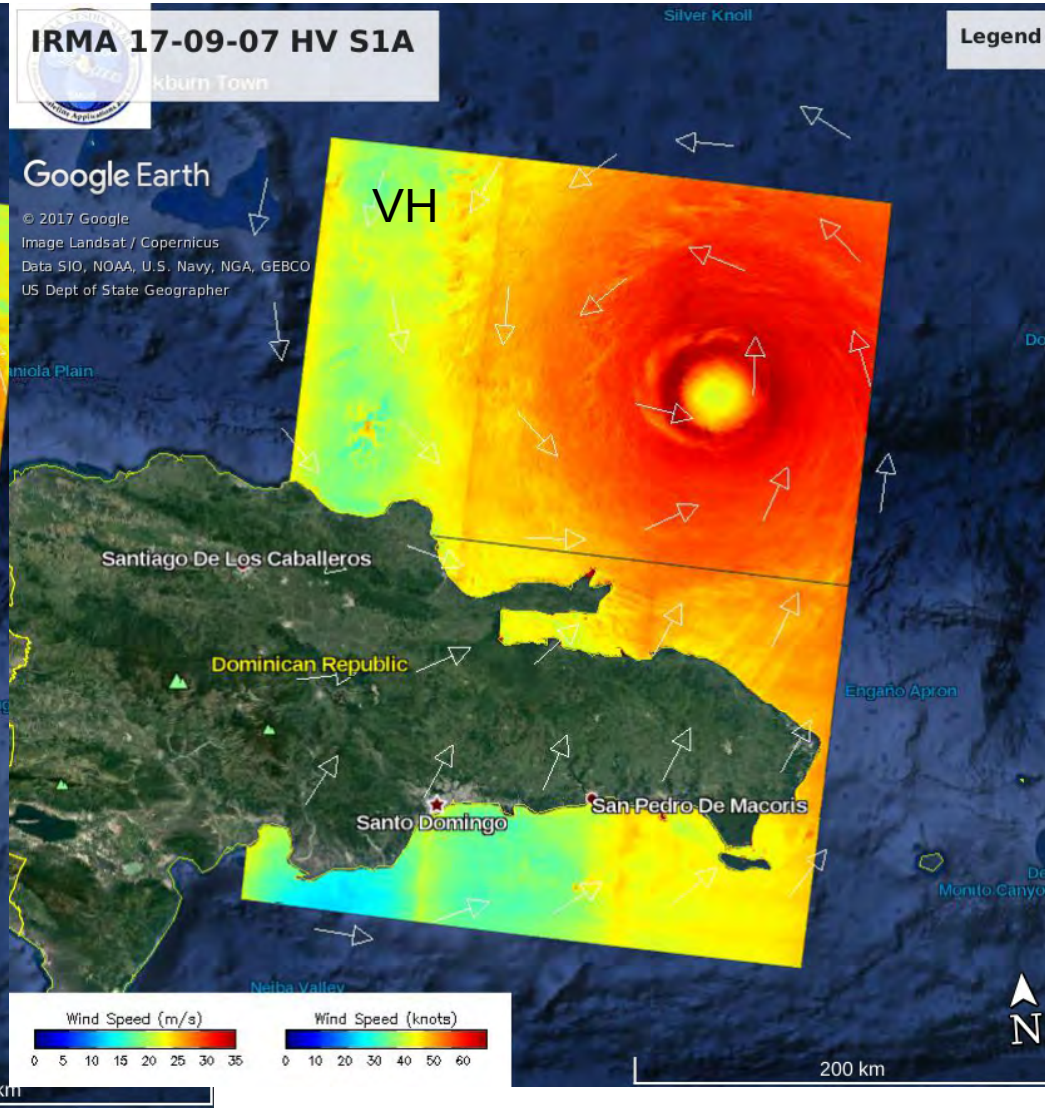
C2-PO
Sigma 0 = 0.586 u10 +35

After, Zhang, Perrie et al, 2017


IRMA-170907-11 S1
Legend
Google Earth
© 2017 Google
US Dept of State Geographer
Data SIO, NOAA, U.S. Navy, NGA, GEBCO
Image Landsat / Copernicus
Sentinel-1 VV/VH Images analyzed
9.9. 23:33:VV
11.9.VV
9.9.VV
R-2, 8.9, 10:53
7.9. 10:30 VH
10.9. 23:25VV
Jose, 11.9. VH
© NIC, SAR WIND, F. Monaldo
Wind Speed (m/s)
0 5 10 15 20 25 30 35
HV/VH
Wind Speed (knots)
0 10 20 30 40 50 60
Wind Speed (m/s)
0 5 10 15 20 25
VV/HH
Wind Speed (knots)
0 10 20 30 40

Irma, u_{10} from VV and VH Channel





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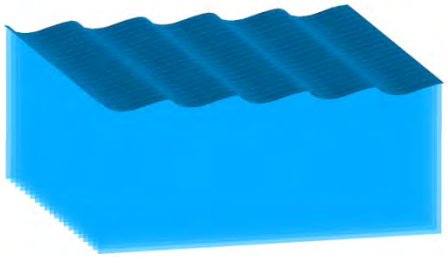
From NIC SAR WIND

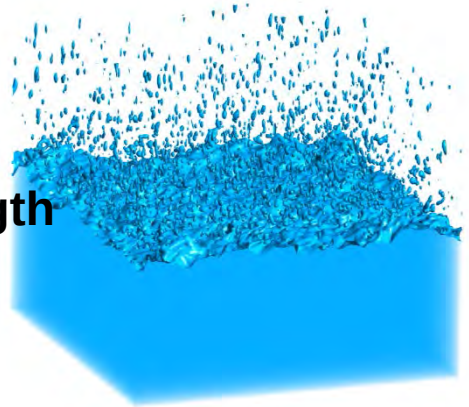
CFD simulation of the air-sea interface

U_{10} ~ 80 ms^{-1}

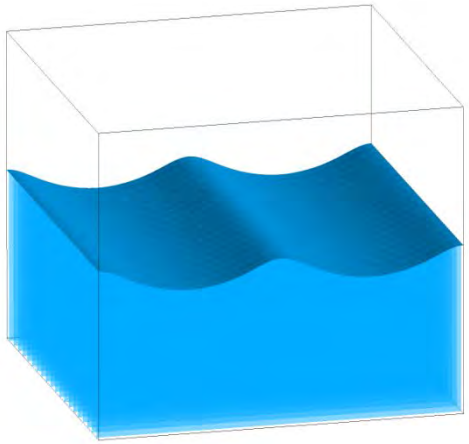
***t* = 0 s**

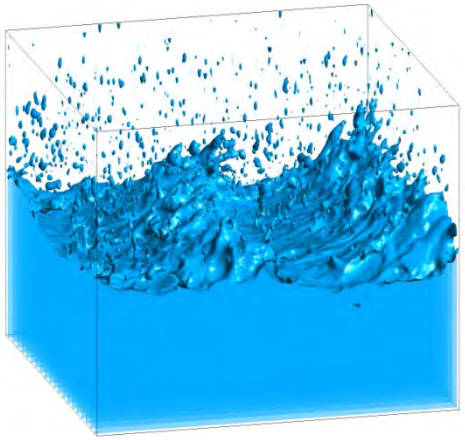
***t* = 0.3 s**





4 cm wavelength

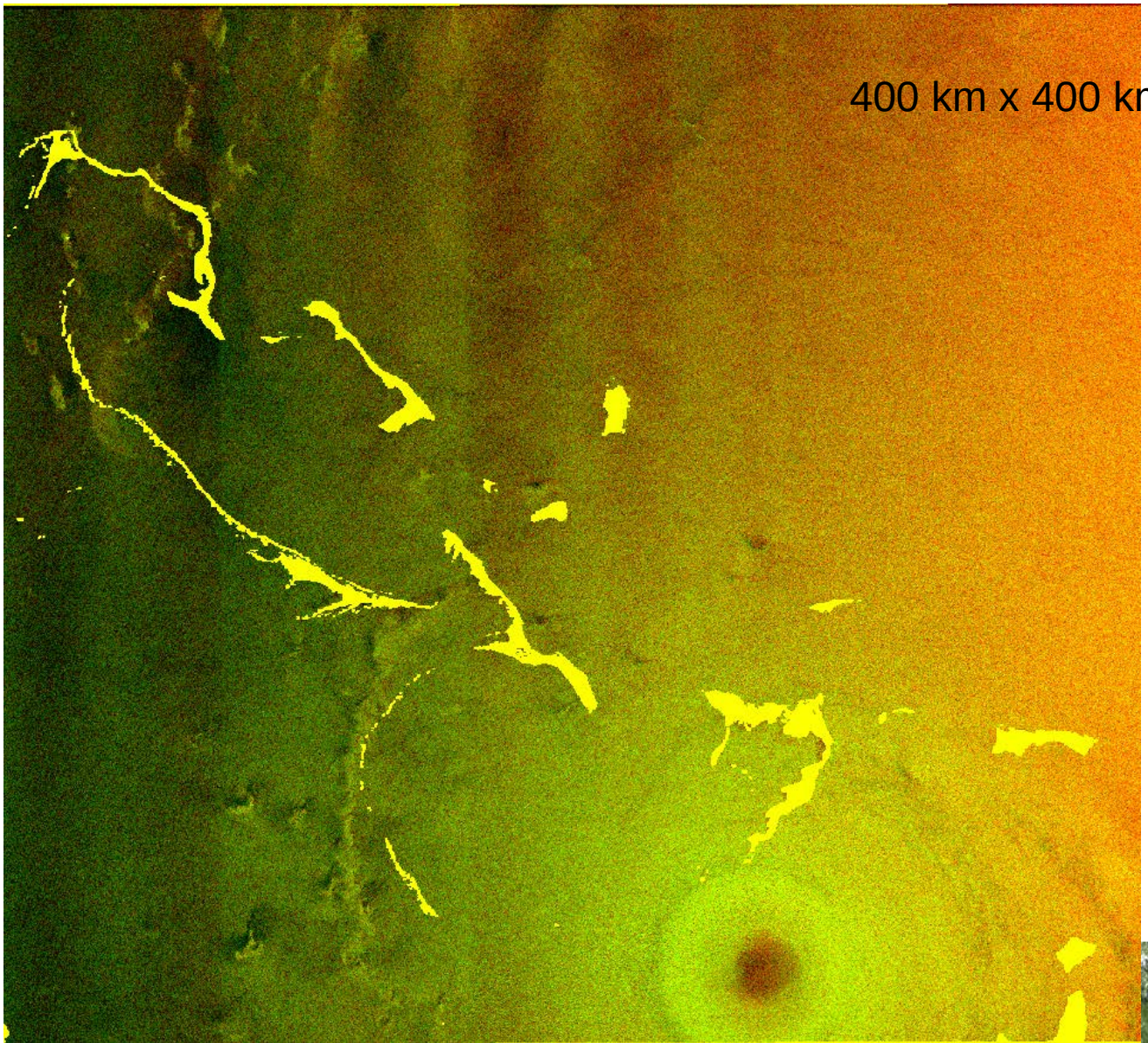




10 cm wavelength

After Soloviev, Lukas, Donelan, Haus,and Ginis (2017)

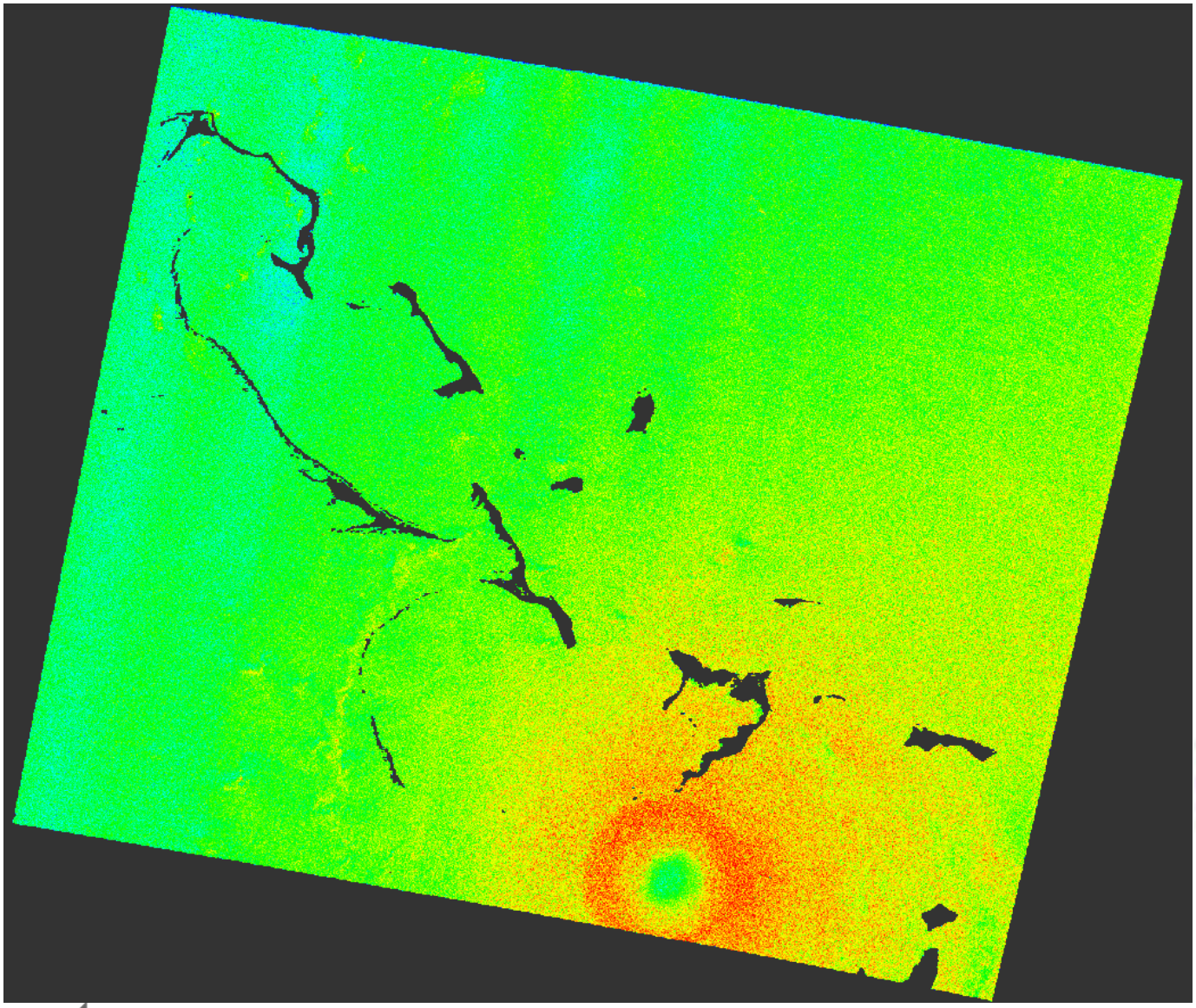
RADARSAT Combination VV and VH



8 Sep 2017
10 53 UTC
HV, ground range
© MDA

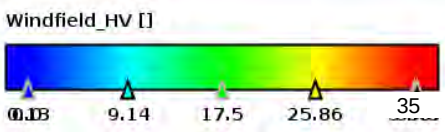
Using
ESA SNAP

Windfield from RADASAT-2 Image of IRMA



8 Sep 2017
10 53 UTC
HV, ground range
© MDA

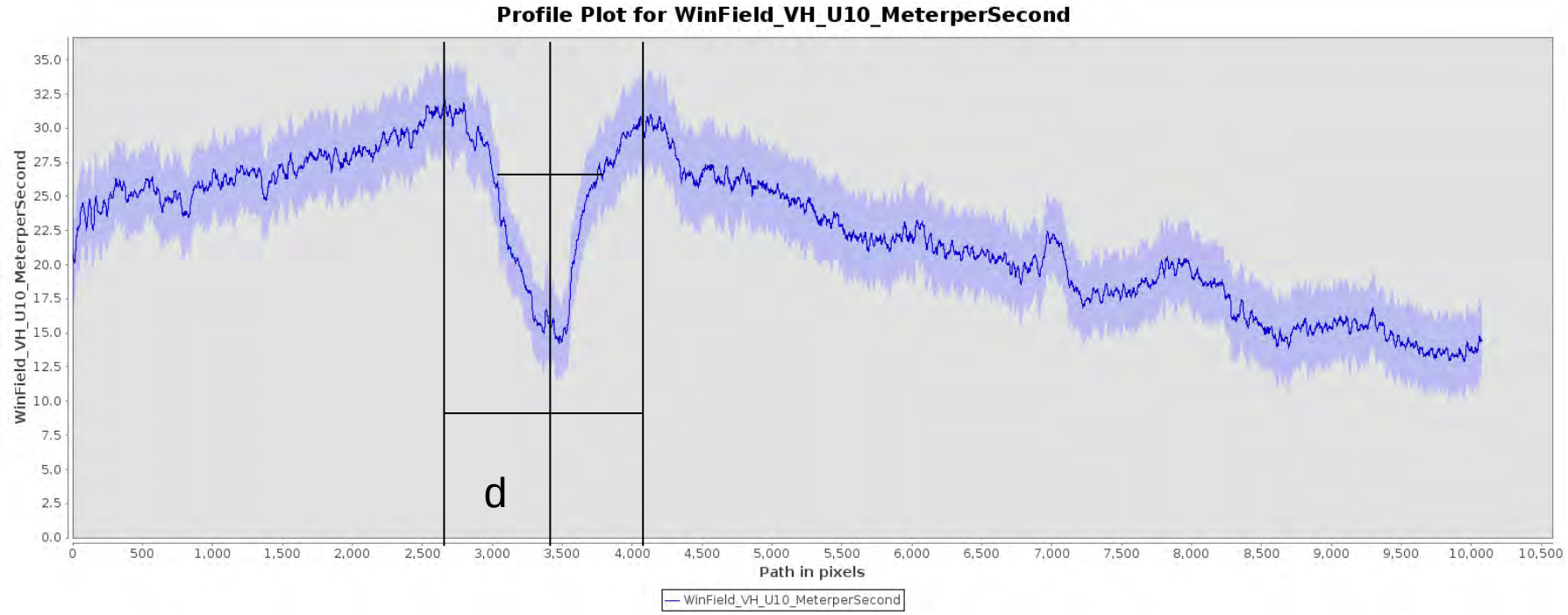
Using ESA SNAP



DLR

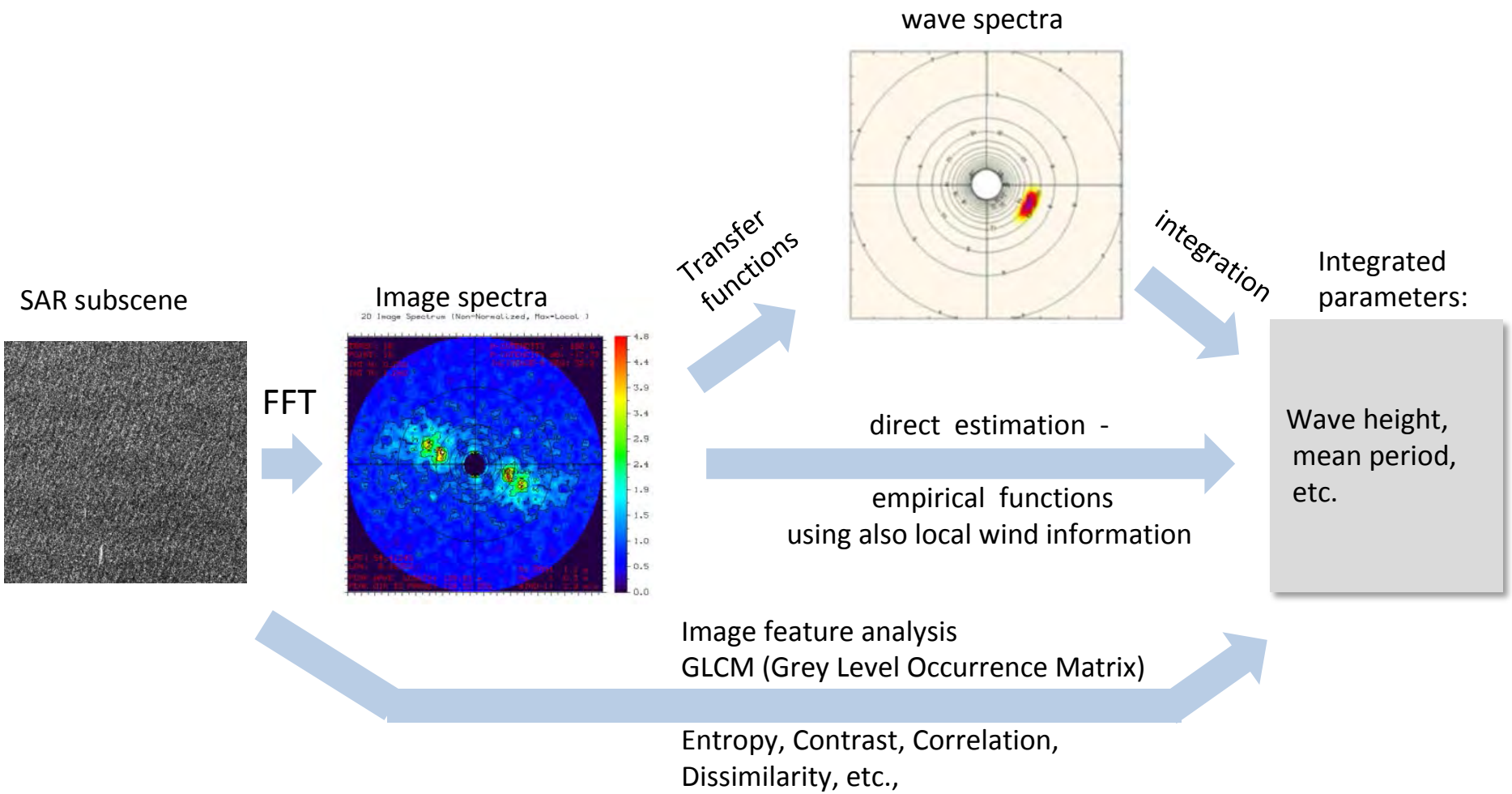
Wind Speed Measurement u_{10} through the Eye with R2

- Maximum Wind Speed ~ 35 m/sec
- Radius of Maximum Wind Speed



Pixel 50m, Diameter d 70 km, Eyesize 35 km

Basic principles of sea state parameter estimation



Quality Control: Buoys (location) and Wave model results (spatial distribution)

sea state estimation from SAR image

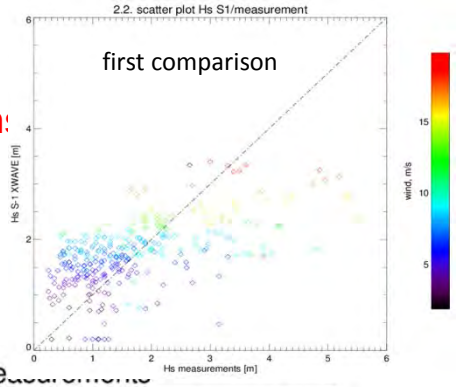
Validation Empirical S-1 Significant Wave Height Algorithm

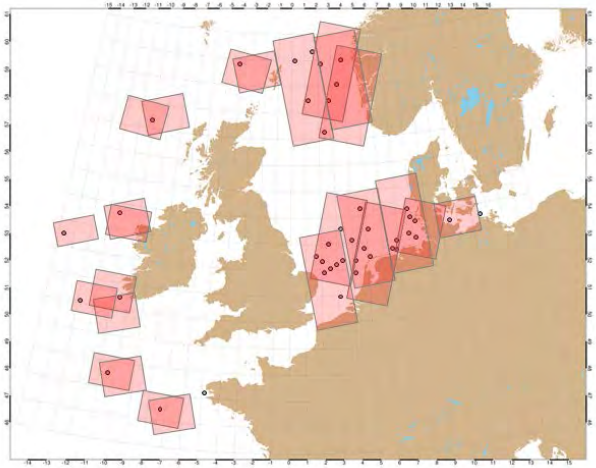
Pleskachvsky et al., 2017

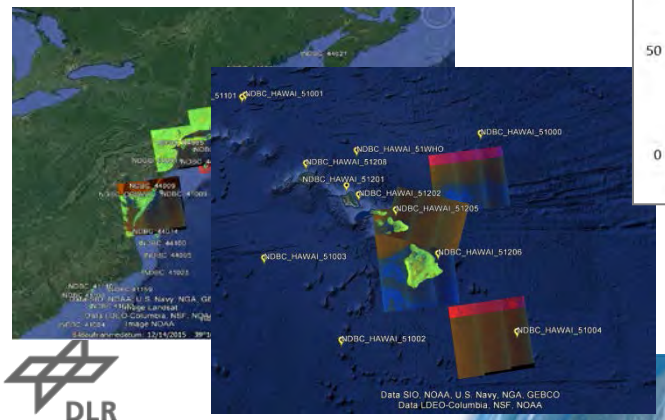
EAST ATLANTICS & North Sea ~300 IMAGES ~ ~40 buoys **~900 collocations**

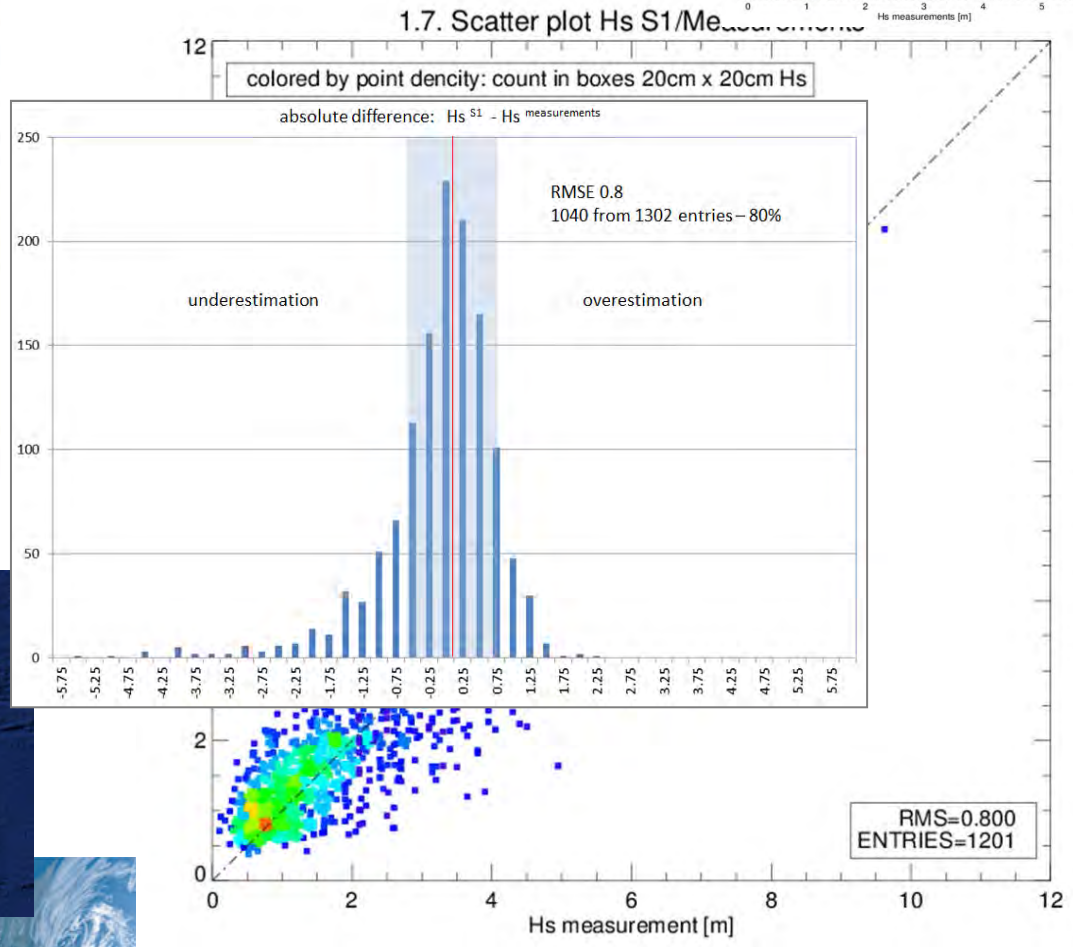
USA EAST COAST ~300 IMAGES ~ 15 buoys ~**400 collocations**

USA HAWAI 49 IMAGES 4 buoys ~**60 collocations**

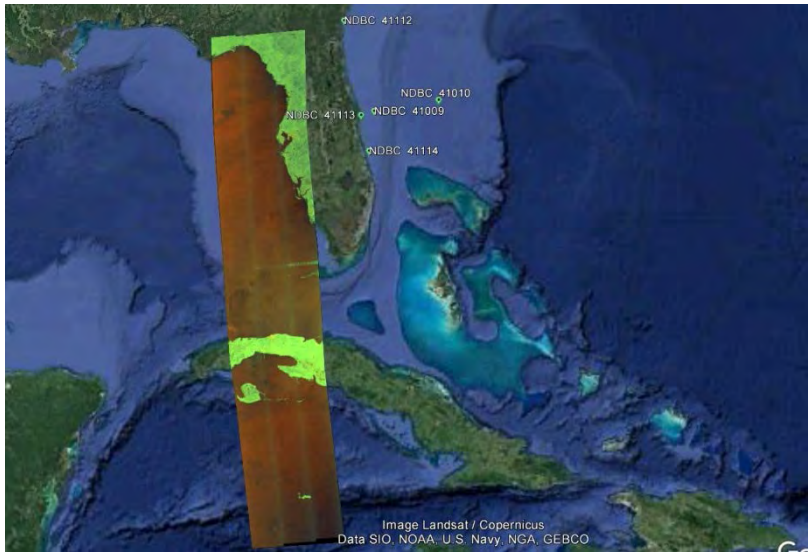


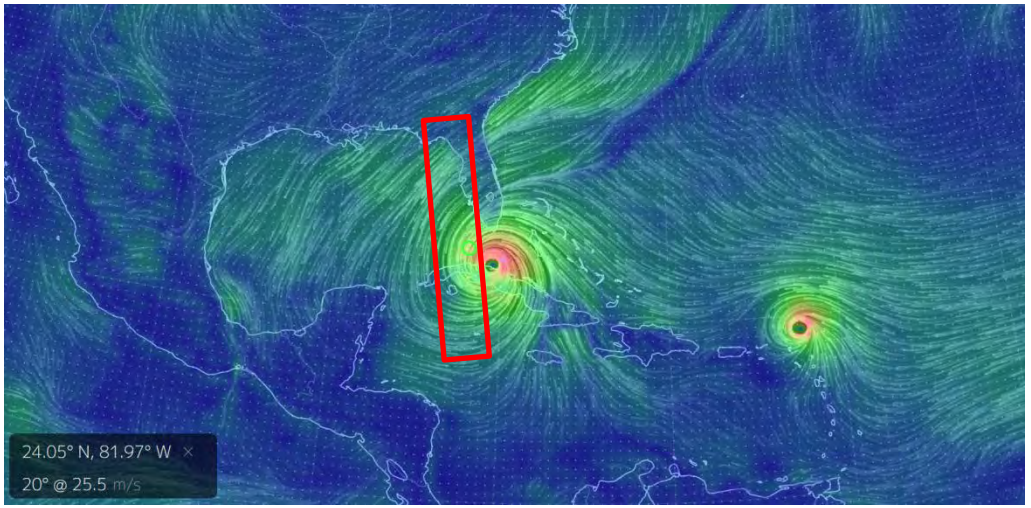


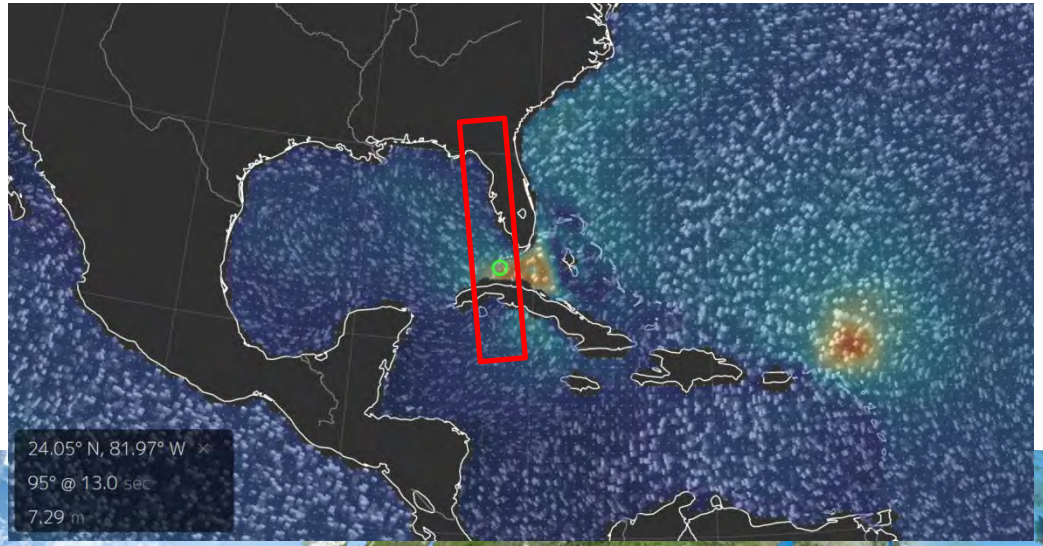




Sentinel Images from this Year´s Hurricane Season Example Sep, 9th





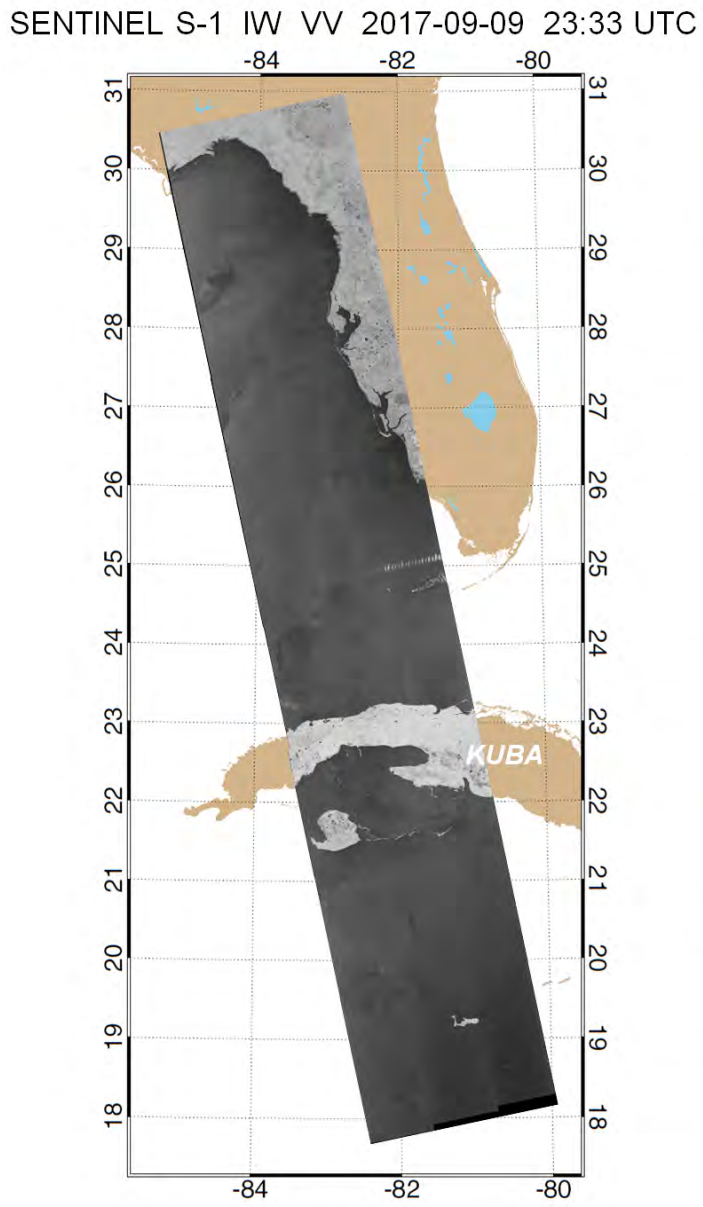


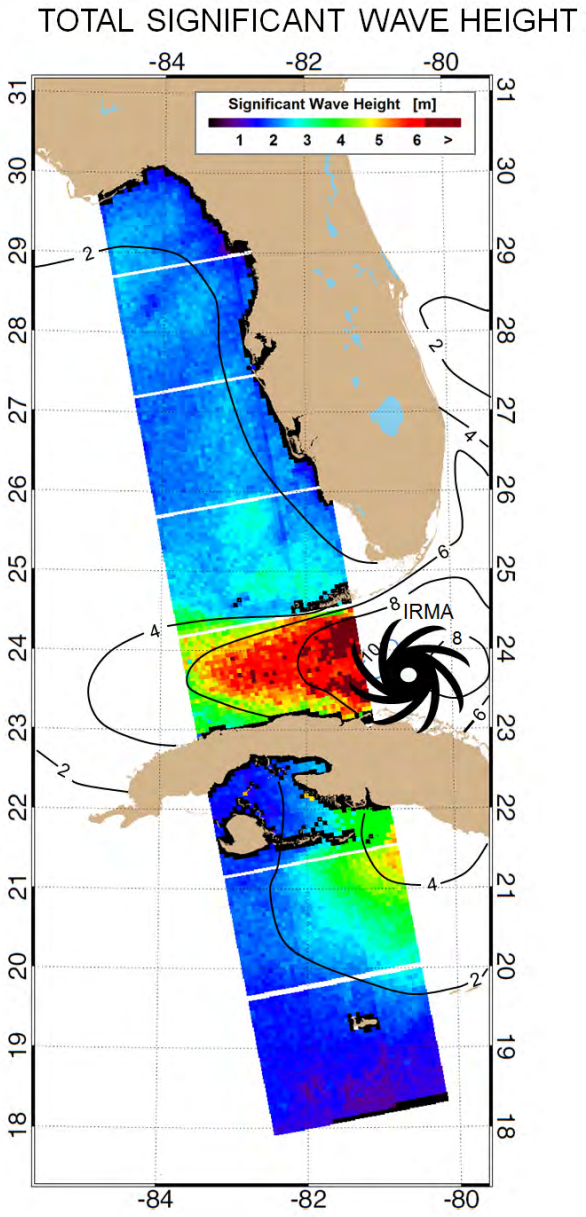
S1-B

2017-09-09 23:33:28
2017-09-09 23:33:57
2017-09-09 23:34:22
2017-09-09 23:34:47
2017-09-09 23:35:12
2017-09-09 23:35:37
2017-09-09 23:36:02
2017-09-09 23:36:27

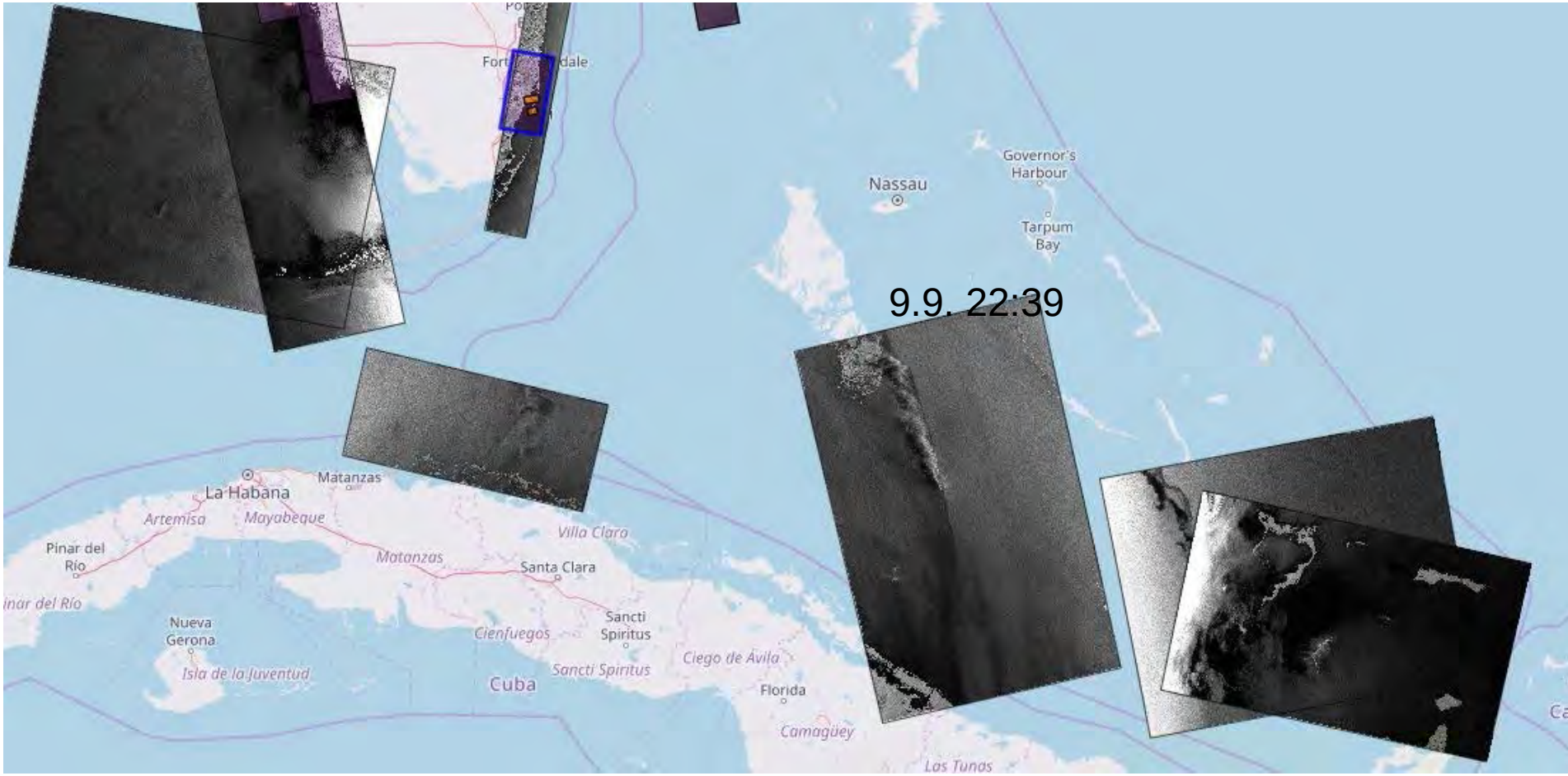
DLR

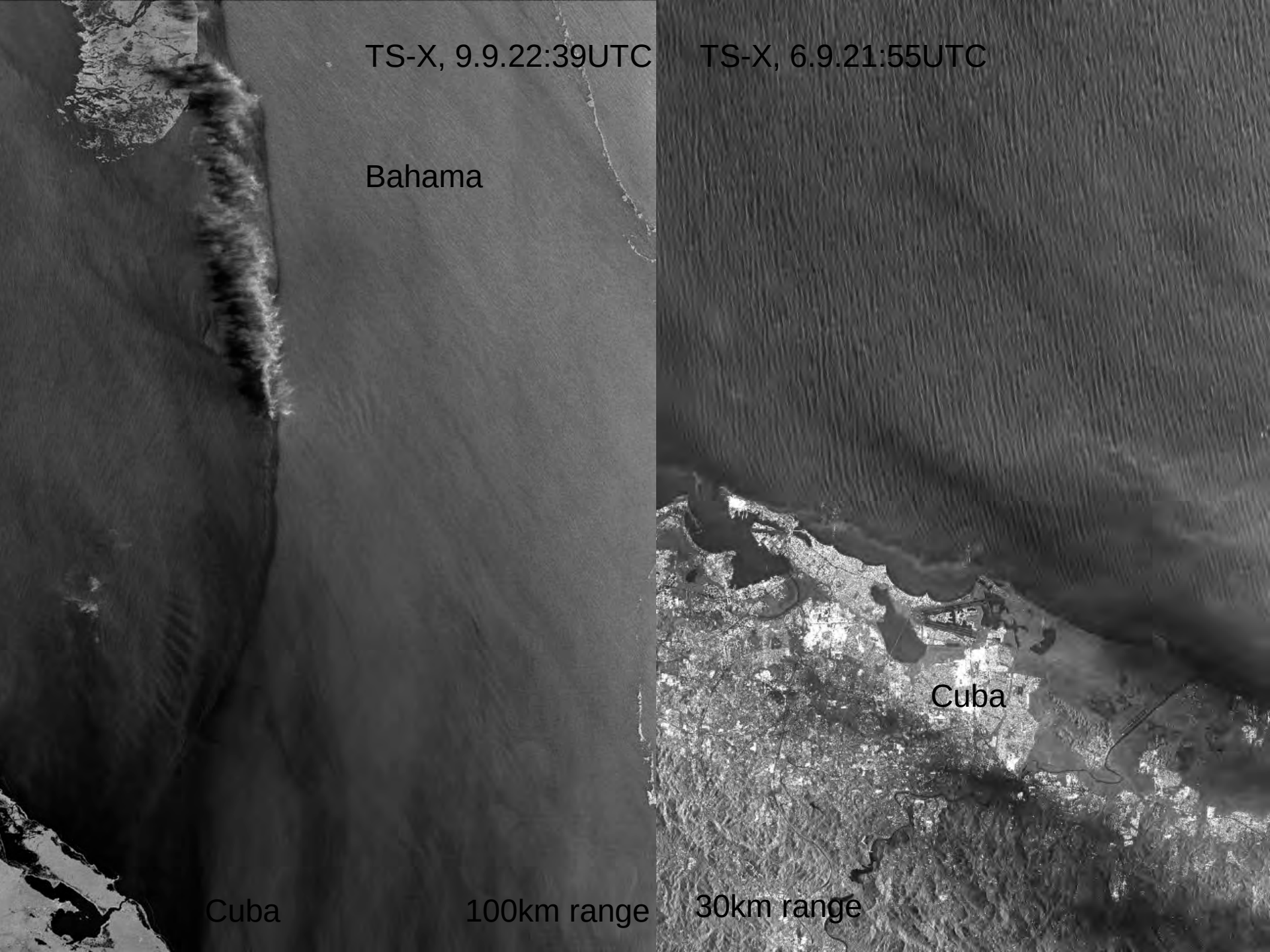
Significant Wave Height under Hurricane IRMA





Images from TerrasAR-X over IRMA




TS-X, 9.9.22:39UTC
Bahama
Cuba
100km range
TS-X, 6.9.21:55UTC
Cuba
30km range

Summary

- We derived Wind Speed from HV channel and Significant wave height using empirical algorithms
- HH, VV Wind Speed measurements saturate at low 20 -30 m/sec depending on range
- HV channel can be used to overcome this problem
- Eye shape different in C- band VV to VH channel
- Sentinel-1 data can be downloaded for free on ESAs website
- X-band data show strong rain and sea surface features
- L band better at measuring in heavy rain and high sea state (ALOS, NISAR, TD-L)

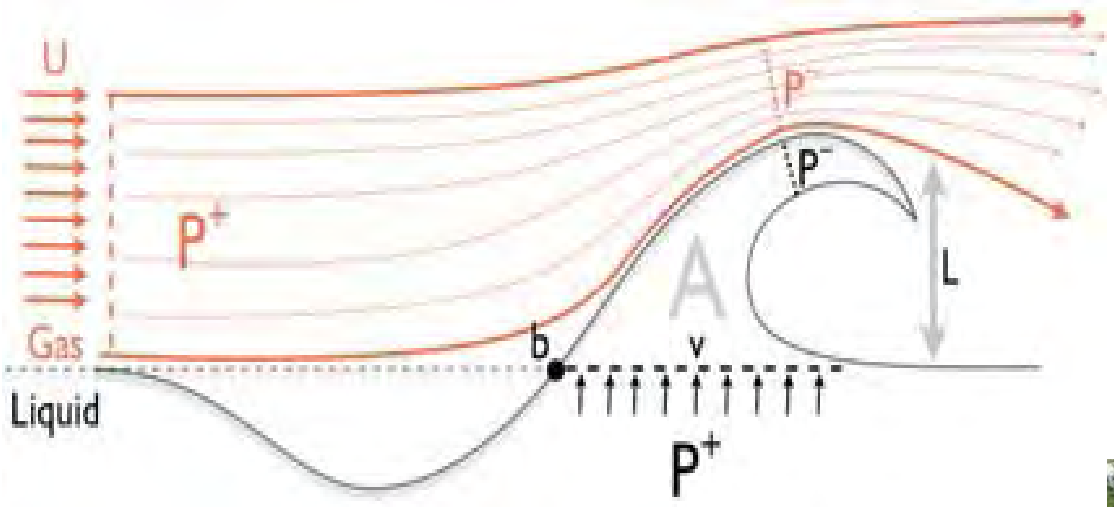
DLR

Backup Slides:

Air-Sea Interface under Tropical Cyclones

• The disruption of the air-sea interface and spume generation under tropical cyclone conditions can be explain by the Kelvin-Helmholtz type shear-layer instability (Koga 1981).

• This instability is able to overcome the stabilizing force of gravity force and surface tension at the air-water interface above ~30 m/s wind speed, corresponding to transition to Category 1 hurricane (Soloviev and Lukas 2010, Hoepffner et al. 2011).



Empirical Geophysical Model Function for Co-Polarization Sigma-0 VV->HH

C-band GMF for Co-Polarized SAR (HH)

The CMOD functions are applicable for radar NRCS acquired in VV polarizations. To apply the CMOD functions for NRCS in HH polarizations, **convertion of the σ_0^{HH} to σ_0^{VV} using the empirical Polarization Ratio (PR) Model** priori to apply the CMOD GMF is often considered.

a) Three PR models which consider influence of the incidence angle on PR are often used.

Thompson model

$$PR = \frac{\sigma_{VV}^0}{\sigma_{HH}^0} = \frac{(1+2\tan^2\theta)^2}{(1+\alpha\tan^2\theta)^2}$$

in which, θ is incidence angle. Thompson *et al.* (1998) proposed α=0.6. Both Vachon and Dobson (2000) and Horstmann *et al.* (2000) concluded that α=1 is suitable for the C-band RADARSAT-1 data.

Elfouhaily model

$$PR = \frac{\sigma_{VV}^0}{\sigma_{HH}^0} = \frac{(1+2\tan^2\theta)^2}{(1+\beta\sin^2\theta)^2}$$

$\beta = 2$ as proposed in [Elfouhaily and Thompson 1999]

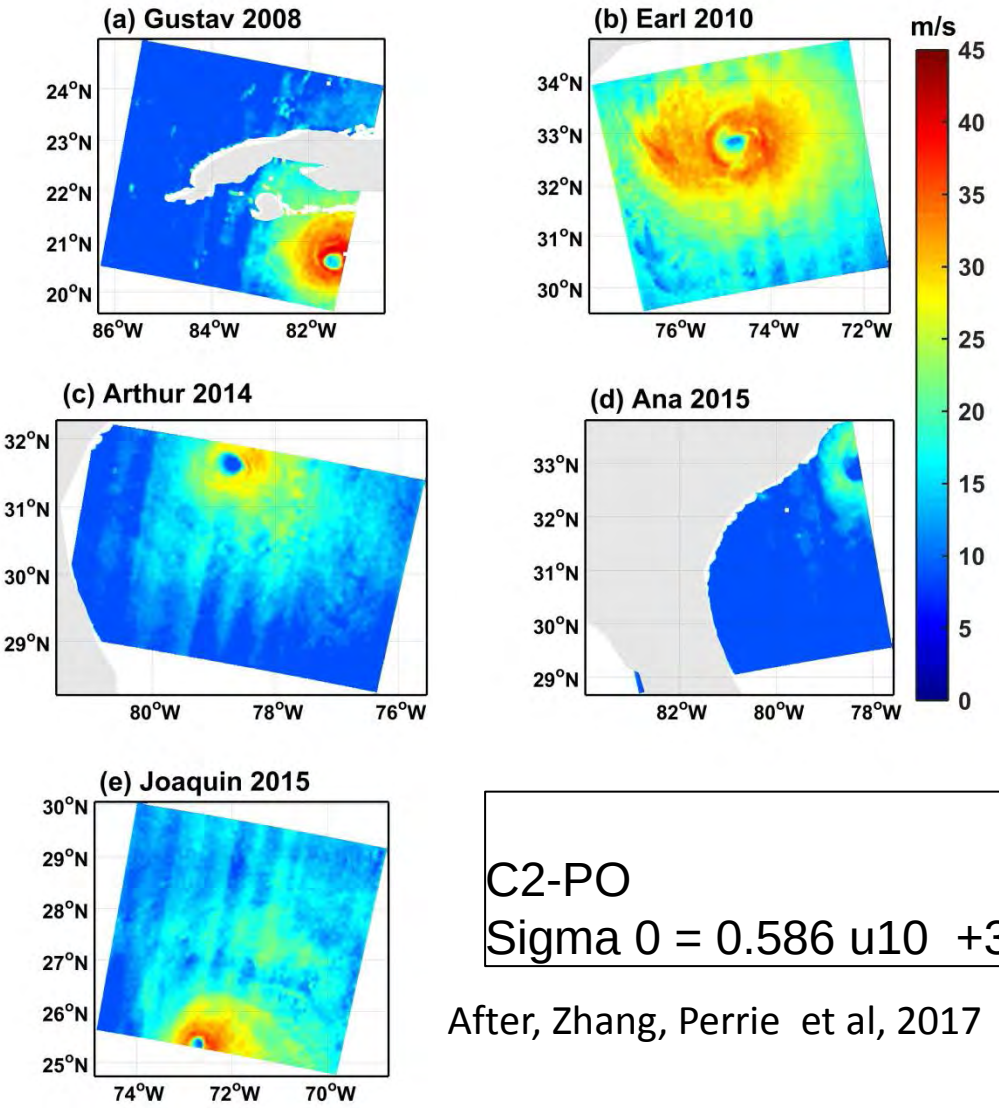
Mouche model

$$PR = \frac{\sigma_{VV}^0}{\sigma_{HH}^0} = C_0 EXP(C_1\theta) + C_2$$

$C_0 = 0.0065, C_1 = 0.1289, C_2 = 0.9928$ as proposed in [Mouch *et al.*, 2005]

b) In addtion, influence of wind speed and sea state on PR are also considered [Mouche *et al.*, 2005; Zhang *et al.*, 2011].

U10 from HV Model Results



- **C-3PO**

C-band Cross-Polarization Coupled-Parameters Ocean (C-3PO) model: $\boldsymbol{\sigma_0 = A(U_{10}) \cdot [1 + b_1(\theta)]}$

$$b_1(\theta) = n_b * \frac{\theta - \theta_{middle}}{\theta_{middle}}$$

linear: $A(U_{10}) = p_1 \cdot U_{10} + p_0$

quadratic: $A(U_{10}) = p_2 \cdot U_{10}^2 + p_1 \cdot U_{10} + p_0$

C2-PO
Sigma 0 = 0.586 u10 +35

After, Zhang, Perrie et al, 2017

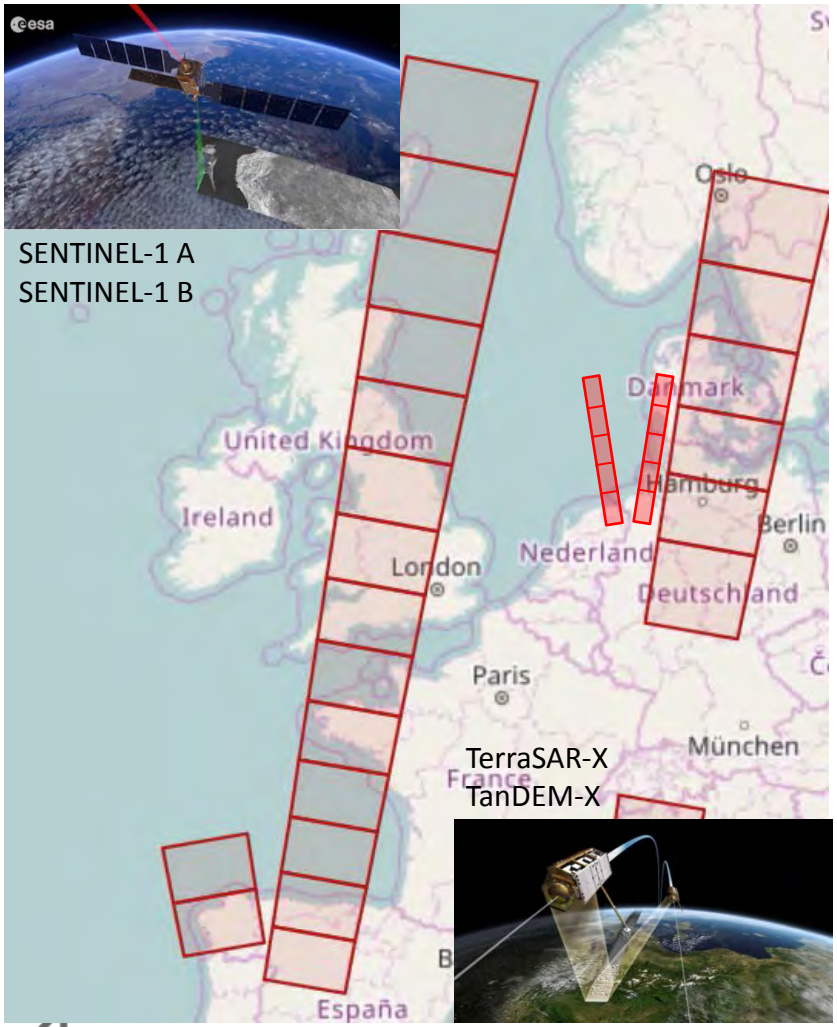
Hurricane surface wind speed retrieved by C-3PO model for the 5 SAR images for:

a) Hurricane Gustav (11:28 UTC, 30 August 2008),
b) Hurricane Earl (22:59 UTC, 2 September 2010)
c) Hurricane Arthur (11:14 UTC, 3 July 2014),
d) Hurricane Ana (23:24 UTC, 9 May 2015),
e) Hurricane Joaquin (10:45 UTC, 3 October 2015).

Respective SFMR tracks within a 30 minutes window are also shown.

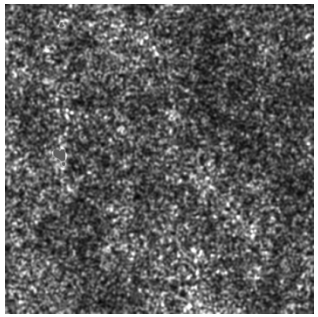
- **blue** curves represent the SFMR tracks
- **cyan** points are the positions with respect to the Best Track.

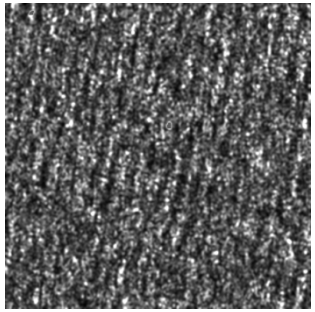
Different SAR Satellites, Different Radar Frequencies more coverage – less resolution



Differences: resolution, bands, platform altitude, ground speed

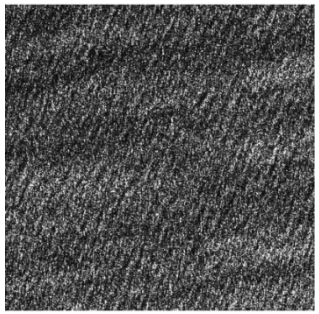
Sentinel-1 A/B IW 250km 10m pixel res.

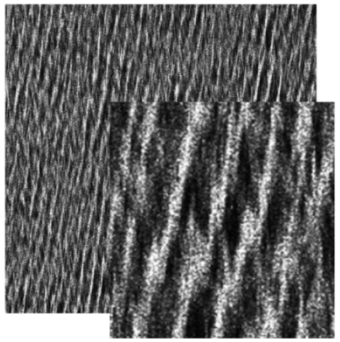




H_s~1.5m
L_p~ 80m

H_s~3.5m
L_p~250m



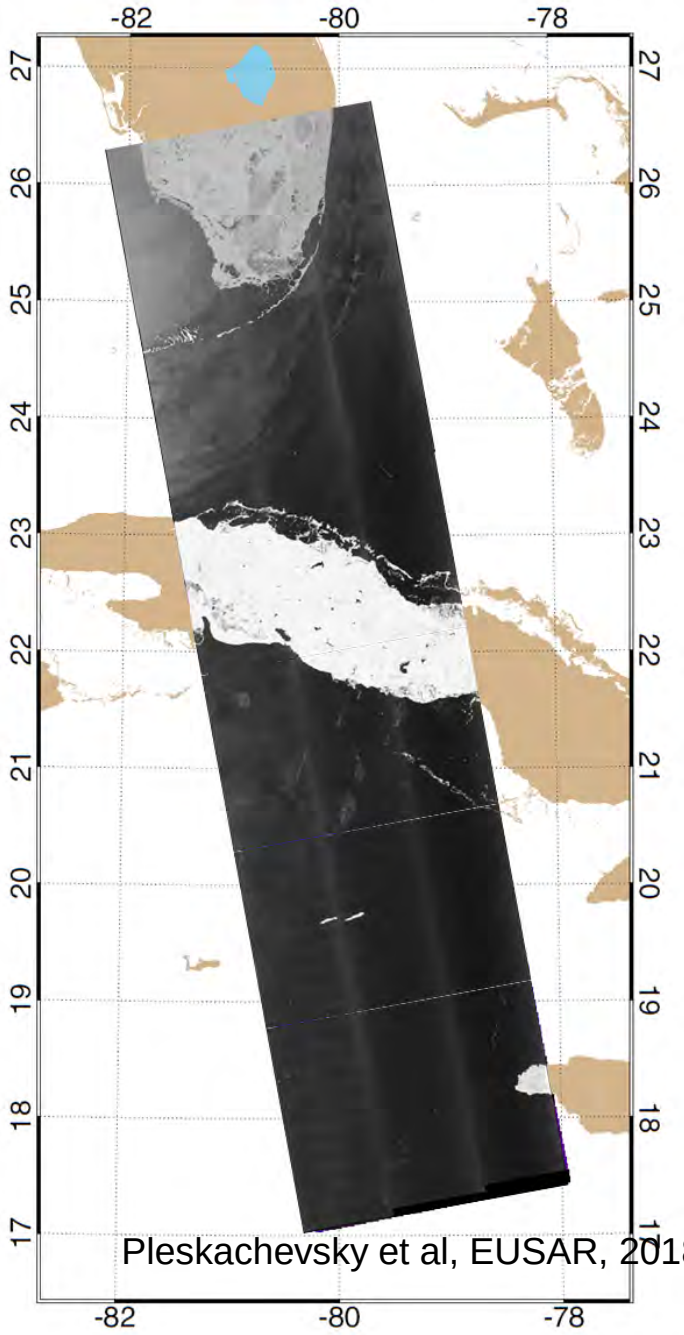


TerraSAR-X StripMap 30km 1.2m pixel res.

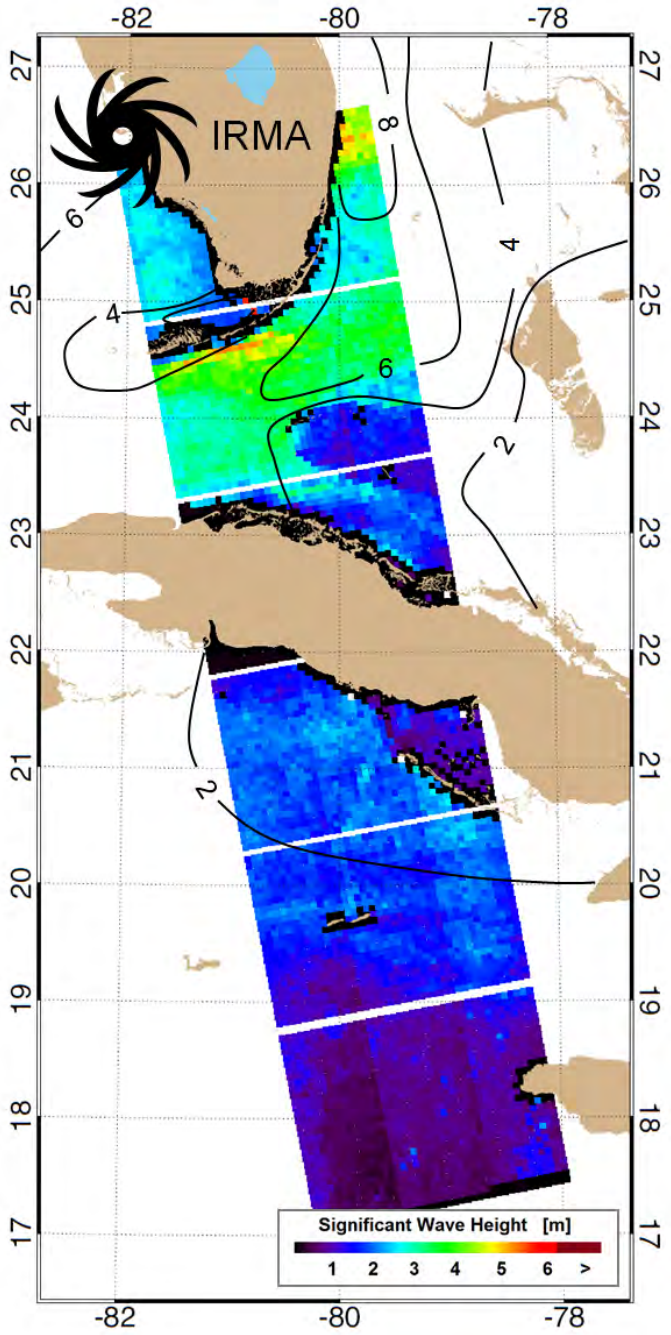
Fig. 14: Sea surface imaging by SAR: different sensors and coverage

DLR.(

SENTINEL S-1 IW VV 2017-09-10 23:25 UTC

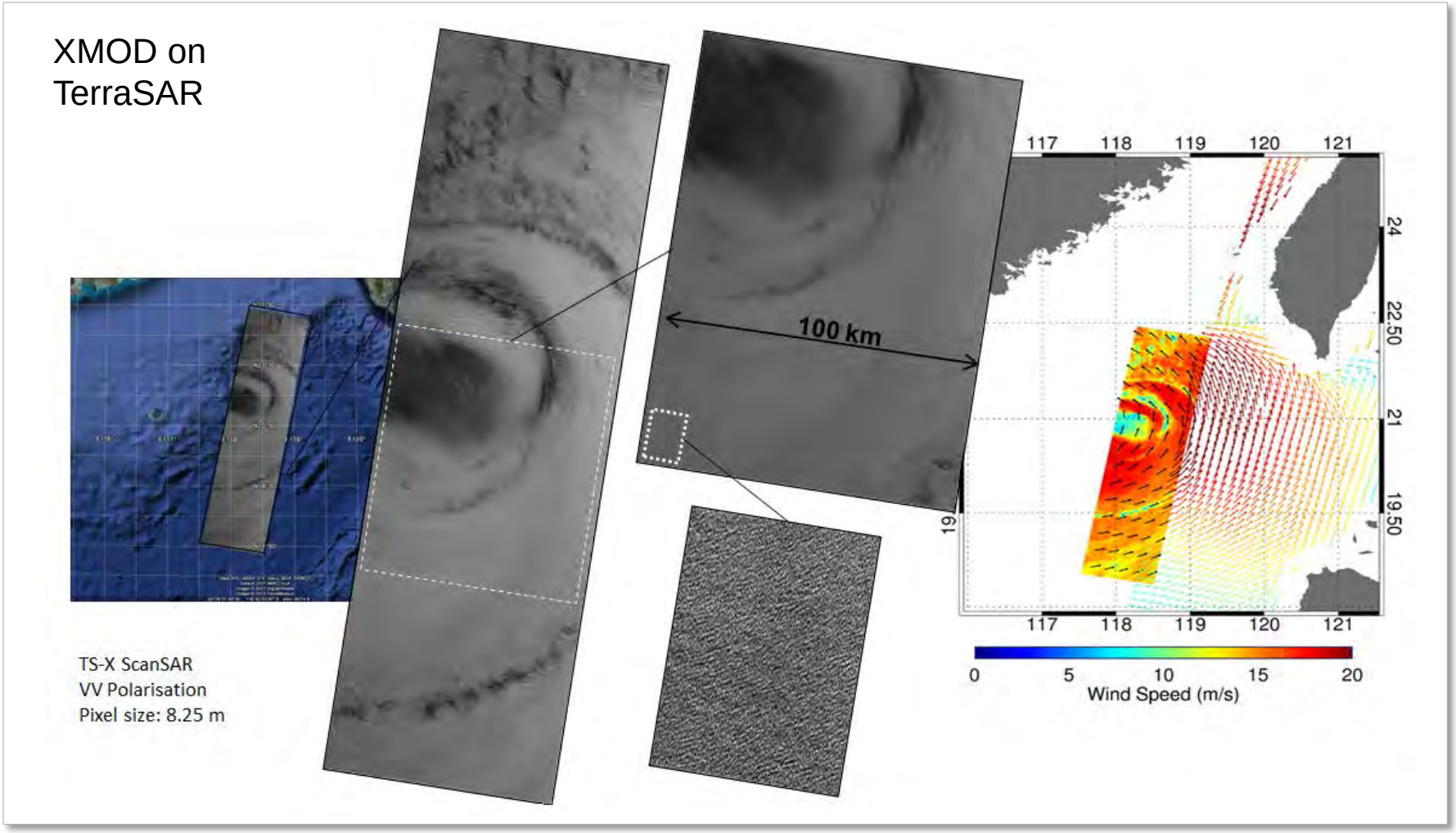


TOTAL SIGNIFICANT WAVE HEIGHT



Pleskachevsky et al, EUSAR, 2018

Wind field from SAR data: Typhoon MEGI



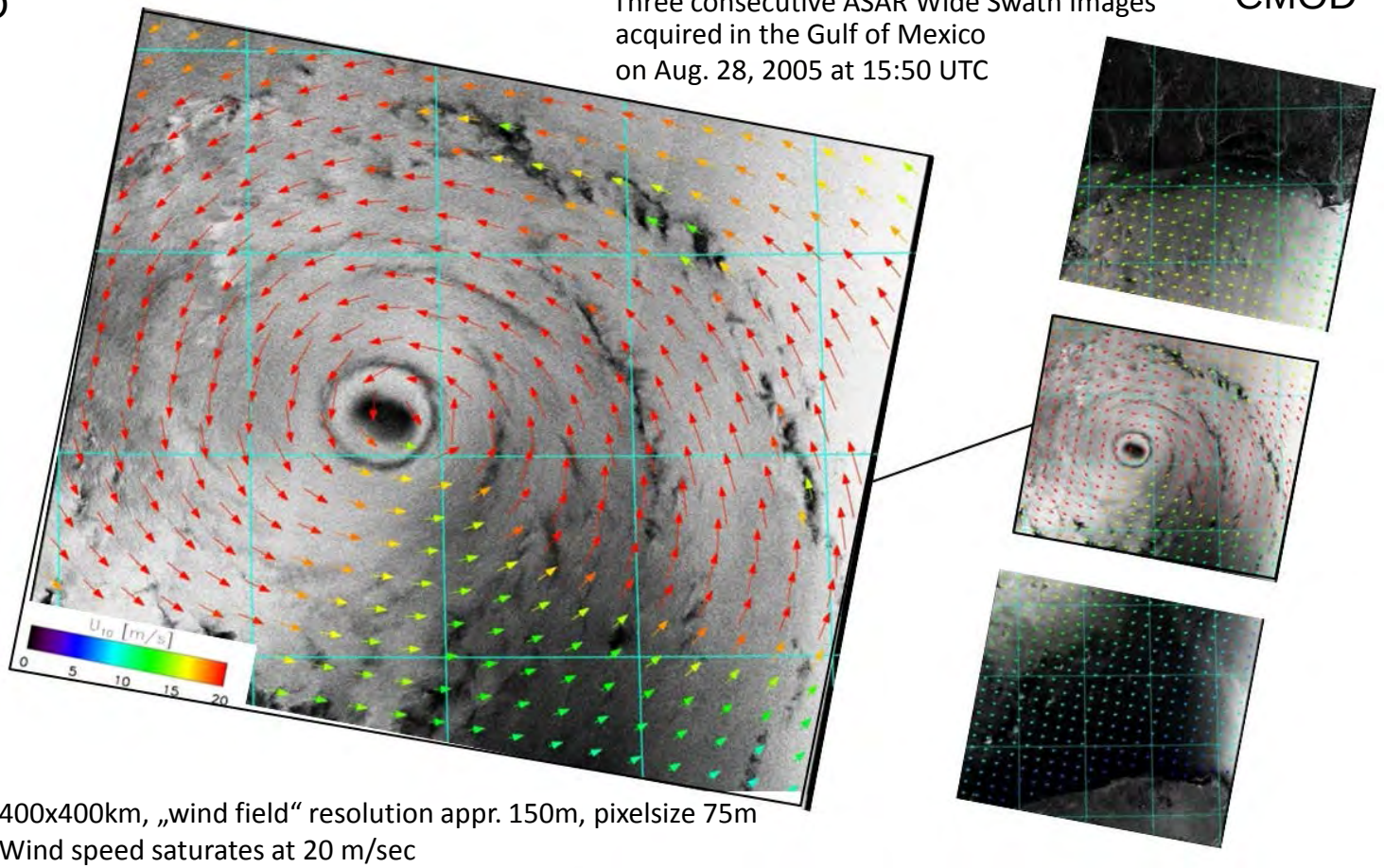
Tropical Cyclone Eye “MEGI” SSW measurement of Typhoon using TSX-SC data (© DLR)

Wind field from SAR data: Hurricane Katrina

CMOD

Three consecutive ASAR Wide Swath Images
acquired in the Gulf of Mexico
on Aug. 28, 2005 at 15:50 UTC

CMOD



400x400km, „wind field“ resolution appr. 150m, pixelsize 75m
Wind speed saturates at 20 m/sec